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An Efficient Access Technique based on Clustering and Resources Sharing for Machine Type Communication over LTE Network

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Abstract: Machine Type Communication (MTC) over the cellular network plays an important role in many smart applications. Long Term Evolutionary (LTE) network is considered the best cellular network for deploying the MTC devices in remote areas because of its high data rate and wide coverage area. The massive access of the MTC devices over LTE network results in poor network performance due to the high collision rate, high retransmission rate, high overhead, high delay, low throughput, and high power wastage. This paper proposes a new access technique to increase the access performance for MTC over LTE network. It is based on the clustering and grouping approach and resources sharing using the capillary network without using cluster head/helper node. In the proposed technique, MTC devices are divided into WLAN groups based on the geographical distance. In each WLAN, an MTC device can ask for uplink resources for data transmission from eNB for individual use or a group use. The MTC device shares the allocated resources with other devices inside its WLAN after finishing its data transmission using Distributed List Hub Polling (DLHPL) MAC protocol. The other devices inside the same WLAN can contend locally on these free resources without querying the eNB. The devices send data frames over LTE using these shared uplink resources without the need to relay it through a head node. The experimental results show that the proposed access technique gives lower collision rate, higher access probability, higher transmission opportunity, higher resources utilization, lower overhead, higher throughput, and lower delay compared with other recent techniques.

Keywords: Machine Type Communication (MTC), Long Term Evolution (LTE) Network, Access Techniques, Clustering and Grouping, Resources Sharing.

1 Introduction

Machine Type Communication (MTC) is a subfield of the Internet of Things (IoT) field [1–8]. The communication, in MTC, is carried out between the devices directly without human intervention. MTC has many applications in a variety of life-related fields such as Smart Grid systems, Health Care systems, Monitoring and Tracking systems, and Intelligent Transportation systems. The majority of MTC applications include many devices distributed on a large scale of the area.

Long Term Evolution (LTE) network [1, 2] which is a standard for 4G wireless broadband technology based on original 3G technologies is one of the best choices as a communication system to deploy MTC devices due to its high data rate, large coverage area, increased scalable network capacity, reduced latency, and backward compatibility with existing GSM and UMTS technology.

Some challenges face the use of LTE networks for MTC communication [1–8]. One of the challenges is high overhead compared with the transmitted data. The MTC devices transmit data in small sizes frequently. The signaling overhead, to establish the connection and the scheduling requests, is larger than the actual transmitted data itself. Most of the power sources in the MTC devices are wasted in the signaling overhead. The second challenge is the congestion in the Radio Access Network (RAN) and Core Network (CN) of the LTE network. The congestion in the RAN takes place when a large number of MTC devices access the evolved Node Base station (eNB). Due to the limitation of the preambles set and resources of the Random Access Channel (RACH) which is used to gain the access to the eNB, the high numbers of MTC devices that try to access the LTE eNB cause a high

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collision rate, high retransmission rate, high overhead, high delay, low throughput and high power wastage.

In LTE network, the User Equipment (UE) uses Random Access Channel (RACH) Procedure (RACH) for: (1) initial connection with eNB to establish a radio link and resource request when no uplink radio resource has been allocated, (2) connection re-establishing when the connection is out and no synchronization between the UE and the eNB, (3) handover operation in which the UE access transits from one eNB to another, (4) downlink data receiving from the eNB side when the UE is connected and synchronized up with the eNB, (5) uplink data transmission to the eNB side when the UE is connected and synchronized up with the eNB, and (6) alerting position to the eNB when the UE is connected and synchronized up with the eNB. There are two types of RACH procedure in the LTE network: [9–12] 1) contention-based and 2) contention-free. Contention-based RACH procedure is used for the initial connection establishment and the connection re-establishment. In contention-based, UEs content on the channel's resources to send their connections requests in which the UE randomly selects a preamble id, from the preambles set that are broadcast from the eNB, to send the preamble message in the PRACH. Contention-free RACH procedure is used when the time is a critical issue such as in the purpose of hand-over process, downlink data arrival, uplink data arrival, and position alerting when the UE is connected and synchronized up with the eNB. In contention-free, the eNB has the control over the device to initiate RACH in which the eNB starts the RACH procedure by triggering the UE to initiate the RACH procedure using a previously allocated preamble id.

Many research papers are proposed to overcome the massive access of the MTC device over the LTE network [13–31]. A set of these papers utilizes the clustering and grouping approach [26–31] which reduces the overload of MTC devices through dividing the devices into Wireless Local Area Network (WLAN) groups and each group has a head as coordinator and relaying node. Cluster head/helper node can be configured to collect the data from the group devices and forward it to the LTE eNB [26–29], or it can be configured to coordinate the access to the LTE eNB [30]. The group internal communications, among the group devices and the cluster head, can be carried out over capillary networks such as WLAN (IEEE 802.11), ZIGBEE, and Bluetooth.

Integrating the capillary network with LTE extends the coverage area, offloads the access on the LTE eNB [23, 24], and also extends the LTE spectrum where the capillary network uses the unlicensed spectrum. The capillary network provides a service for mobile devices in a short distance, few meters and up to tens of meters, with a data rate lower than the LTE. Deploying the capillary network is a compromised solution that offloads the LTE RACH and results in low delay and low energy consumption [25].

Zhou et al. in [26] proposed an access method based on the clustering scheme to eliminate the impacts of the overload of the extensive access of the MTC device on the LTE/LTE-A network. To relay the aggregated data to the eNB, the cluster head initially gets uplink resources from the eNB. If the cluster head is not synchronized with the eNB, it performs the RACH procedure before sending the uplink resource scheduling request. In this method, the cluster head aggregates a specified number of data packets from the other cluster's members. Then, it performs the RACH procedure, requests Uplink resources, and relays it to the eNB. This scheme reduces the access load on LTE eNB, reduces preambles collision rate, and reduces RACH procedure delay by allowing only the cluster head to transmit directly to the LTE network. This method suffers from the single point of failure, the aggregation and relaying overhead, extensive power consumption, and the high queuing delay in cluster head buffer in the case of low traffic due to waiting for the arrival of a specified number of data packets.

In [27] Shariatmadari et al. proposed a clustering-based method based on the proposed method of Zhou [26]. In this method, the cluster head performs the RACH procedure, requests Uplink resources, and relays data packets to eNB after D seconds from the first packet arrives in the buffer instead of waiting for the arrival of a specified number of packets. This method reduces the queuing delay compared with the method in [26], reduces the MTC access load on eNB, and reduces the preamble collision rate. But it suffers from the single point of failure, the aggregation and relaying overhead, extensive power consumption, and minimum queuing delay of D seconds.

Kim et al. in [28] proposed a clustering-based method based on the proposed methods of Zhou [26] and Shariatmadari [27]. In this method, the cluster head starts performing the RACH procedure when the first data packet arrives at the buffer and continues in aggregating data packets from the cluster's members. Then, the cluster head relays all data packets in the buffer after getting Uplink resources from eNB. This scheme reduces the queuing delay, reduces the MTC access load on eNB, and reduces the preamble collision rate. But it suffers from the single point of failure, the aggregation and relaying overhead, extensive power consumption, and it has less effect at low load.

In [29] Sahu et al. proposed a clustering-based method that reduces the number of uplink resource requests using an adaptive compression algorithm. In this work, the traffic is classified into delay-tolerant and delay-sensitive traffic. The cluster head aggregates the delay-tolerant traffic and compresses the aggregated data before relaying it to the eNB which decompresses the data before routing it. This method reduces the required uplink resources through the compression algorithm, reduces the MTC access load on eNB, and reduces the preamble collision rate, but it suffers from the single point of failure, the aggregation and relaying overhead, extensive power consumption, and presents a new delay for data packets compression.

Lin et al. in [30] proposed a clustering-based method to coordinate the UEs access inside each cluster by the cluster head. The UE, that wants to perform the RACH, sends an access request to the cluster head. The cluster head stores the UEs requests in a queue. Every RACH slot, the cluster head selects only one UE to perform the RACH. This method reduces the MTC load on eNB and reduces the preambles' collision rate, but it suffers from the single point of failure, the overhead of RACH requests managements, and the increase of the access delay.

The methods that are proposed in the clustering and grouping have the following advantages: (1) it significantly reduces the load of MTC over LTE through allowing only the cluster head to transmit directly to the LTE network, (2) it reduces the preamble collision rate, and (3) it reduces the RACH procedure delay. But these methods have some limitations as follows: (1) it suffers from the aggregation and relaying overhead and extensive power consumption, (2) it suffers from the high transfer delay in the case of high devices number in the single cluster due to the long waiting time in the cluster head buffer before relaying it to the eNB, (3) the presented overhead due to the election process of the cluster head in the case of selecting the head dynamically, and (4) the single point of failure, all-time availability for the cluster head, and the power consumption for relaying the cluster devices data frames in case of using fixed cluster head.

In this paper, a new method is proposed to decrease the effect of the MTC massive access on the LTE network by using the clustering concept that integrates the devices' capillary Wi-Fi network (WLAN) with the LTE network without using a cluster head. In the proposed method, the device inside the WLAN that succeeds in getting resources from the LTE network shares these resources with its WLAN devices. To guarantee fairness among the different groups and prevent the uplink resources starvation, each resource is used for a fixed interval, and then it is released by the LTE network. To manage the resources sharing inside the WLAN group, a Hub Polling Medium Access Control protocol that is called Distributed List Hub Polling protocol (DLHPL) which we proposed in [32] is used. DLHPL provides a method to form the polling list in a distributed and dynamic manner between the stations instead of forming it centrally by the Point Coordinator that is used in the Robust Super Poll protocol [33]. In addition, it makes a balance in power consumption between the stations because all stations contribute to the polling list formation. DLHPL decreases the overhead and increases the throughput by eliminating broadcasting the polling list every superframe and by eliminating the use of the chaining mechanism that is utilized in the Robust Super Poll protocol in which all the remaining polling list is appended to every data frame that is sent by every station. Throughput and overhead analysis of DLHPL is proposed in [32]. A Delay analysis of DLHPL is proposed in this paper. The devices inside any group can request uplink resources directly from the LTE network in the case of no uplink resources are shared on the group and also in case of the high contention inside the group.

Unlike the previous cluster-based methods, the proposed method does not use a cluster head. All the devices inside the WLAN can send their data frames directly using the uplink resources that are shared in the WLAN without relaying it to a cluster head. The proposed method intends to reduce the access delay, to reduce the total average transfer delay, to reduce the overhead, to increase throughput, to avoid the single point of failure, to save the battery power consumed in the aggregation and relaying operations, and to provide D2D communication inside the group.

The remaining of this paper is structured as follows: Section 2 reviews the DLHPL protocol. Section 3 provides the mathematical delay analysis of the DLHPL protocol. Section 4 presents the proposed access technique. Finally, Section 5 provides the experimental results of the proposed access technique.

2 Distributed List Hub Polling MAC Protocol

Distributed List Hub Polling (DLHPL) is a hub polling MAC protocol for Wireless Local Area Network (WLAN) [32]. It is used in this paper to manage the resources sharing inside the WLAN group. Unlike the Robust Super-Poll (RSPL) MAC [33] that deploys the hub polling mechanism in a partially decentralized manner using Point Coordinator (PC), DLHPL deploys the hub polling mechanism in a fully decentralized manner without the existence of a PC. DLHPL deploys the hub polling approach in a completely distributed manner by: (1) Creating and storing the polling list, which contains the transmission order of the devices, in a distributed way among the devices instead of creating and storing it centrally in PC. (2) Any device starts its transmission after noticing that the device that precedes it has finished transmission without the need to receive a polling message from PC.

Time, in DLHPL, is composed of frames called super frames. Each super frame consists of a Contention Period (CP) and a Contention Free Period (CFP). The CP has a fixed length. Only new devices that want to join the polling list or devices that have critical data are allowed to use CP.

At the end of the CP, the first device in the polling order broadcasts a Beacon to inform all devices of the start of the CFP then it transmits its data frame appended by the next device address. In CFP, each device transmits only in its transmission order. On receipt of the Beacon, all other devices set the Network Allocation Vector (NAV) flag and track the channel traffic to detect its transmission order. NAV is used to block channel access by the devices out of their order. Any device starts the transmission after it finds its address matches the next address that is appended to the previous device data frame. At the end of the CFP, the last device in order to broadcast the CFEnd frame to inform all devices of the start of a new CP.

The polling list of DLHPL is distributed between the devices in which each device stores the priority and the address of the previous and the next devices in the polling order. The order of the device in the polling order is identified by the priority value. The DLHPL priority value is calculated using three QoS parameters: the real time, accuracy, and priority. DLHPL priority consists of 3 bits in which the most significant bit represents the real time, the second bit represents the accuracy, and the least significant bit represents the priority which classifies the priority into 8 classes.

To join the distributed polling list, the device broadcasts a join request frame including the priority value of the device. On receipt of the join request, all other devices process the request and only one device accepts the join request. It is assumed that the device with a low priority value has a higher priority. Based on the priority value, the device request can be accepted, and the device is added to the first of the list, the last of the list, or previous to another device. It is accepted as first if its priority value is less than the priority value of the first one in the distributed polling list. It is accepted as last if its priority value is greater than the priority value of the last one in the distributed list. Finally, it is accepted as previous to the device, i, if its priority value is less than or equals the priority value of the device, i, that accepts the request and greater than the priority value of the device, i, previous. The device that accepts the join request broadcasts an accept request frame including the address and the priority values of the previous device and edits the priority and the address values of its previous and next as needed.

The device can leave the distributed polling list by broadcasting a disjoin frame. The disjoin frame contains the previous device's priority and address and the next device's address. On receipt of the disjoin frame, both the next and previous devices update their addresses and priorities. The next device updates its previous device address and priority to the attached previous address and priority. The previous device updates its next device address to the attached next address.

DLHPL has several strengths that make it the best choice as WLAN MAC protocol as follows [32]: (1) it provides bounded delay, (2) each device transmits in its order with no collision, (3) it is fully distributed where the polling list is created and stored distributedly and dynamically among devices without the need to PC, and (4) it provides the service with low overhead and high throughput compared with its predecessor RSPL MAC protocol.

3 The Proposed Delay Analysis of DLHPL

Throughput and overhead mathematical analysis of DLHPL protocol is proposed in [32]. This section presents a new mathematical analysis of the packet delay for DLHPL which is not introduced in [32]. This analysis is needed in this paper to get indications about the delay that is introduced by DLHPL when it is used to manage the resources sharing inside every WLAN group.

The expected packet delay at node i , T_i, can be obtained by the following equation [34]:

$$T_i = P[EQ] \times \overline{T_{i,EQ}} + P[NEQ] \times \overline{T_{i,NEQ}} \tag{1}$$

Where $\overline{T_{i,EQ}}$ is the expected packet delay at node i, if the arrival finds the i^{th} device buffer is currently empty, $\overline{T_{i,NEQ}}$ is the expected packet delay, if the arrival finds the i^{th} device buffer is not empty, and $P[EQ]$ and $P[NEQ]$ are the probabilities of empty and non-empty buffer respectively.

$P[EQ]$ and $P[NEQ]$ are obtained as follows:

$$P[NEQ] = \lambda \mu$$

Where λ is the arrival rate per second and μ is the device service rate and it is given by $\frac{1}{T_{SF}}$. Where T_{SF} is the super frame time. Then

$$P[NEQ] = \lambda T_{SF} = \rho \tag{2}$$

Where ρ is the utilization.

$$P[EQ] = 1 - P[NEQ] = 1 - \lambda T_{SF} = 1 - \rho \tag{3}$$

$\overline{T_{i,EQ}}$ can be obtained by the following equation:

$$\overline{T_{i,EQ}} = \overline{W_{i,EQ}} + T_L \tag{4}$$

Where $\overline{W_{i,EQ}}$ is the packet waiting time at the i^{th} device buffer when the device buffer is empty and T_L is the average transmission time.

T_L is given by:

$$T_L = \frac{\frac{1}{\alpha}}{R} \tag{5}$$

Two cases are considered to evaluate $\overline{W_{i,EQ}}$ value: Case (1): the target packet arrives to the buffer before the device receives the polling order in the current super frame; Case (2): the target packet arrives to the buffer after the device receives the polling order in the current super frame. Therefore $\overline{W_{i,j,EQ}}$ is found using the following equation:

$$\overline{W_{i,j,EQ}} = P[C1] \times \overline{W_{i,j,EQ,C1}} + P[C2] \times \overline{W_{i,j,EQ,C2}} \tag{6}$$

Where $P[C1]$ and $P[C2]$ are the probabilities of case 1 and case 2. $\overline{W_{i,j,EQ,C1}}$ and $\overline{W_{i,j,EQ,C2}}$ are the packet waiting time in case 1 and case 2, respectively.

Consider that the i^{th} device polling order is i and consider that j devices, of i-1 devices, are polled and transmitted data packets before the i^{th} device in the current super frame.

If the packet arrives at the device buffer before receiving its poll, the packet waiting time value is within the uniform interval:

$$[0, iT_V + j(T_L + T_K) + (i-1-j)T_N]$$

Thus, $\overline{W_{i,j,EQ,C1}}$ can be given by:

$$\overline{W_{i,j,EQ,C1}} = \frac{iT_V + j(T_L + T_K) + (i-1-j)T_N}{2}, j = 0,1,2,...,i-1 \quad (7)$$

Where T_V, T_K, and T_N are the transmission time of the polling overhead, acknowledgment frame, and NTS frame, respectively.

Considering that the arrival instant in any packet relative to the start of its super frame is uniformly distributed, then, $P[C1]$ can be obtained by:

$$P[C1] = \frac{iT_V + j(T_L + T_K) + (i-1-j)T_N}{T_{SF}} \quad (8)$$

If the packet arrives after the device polling, the target packet waits a new super frame. Thus, $\overline{W_{i,j,EQ,C2}}$ can be obtained by:

$$\overline{W_{i,j,EQ,C2}} = \frac{T_{SF} - (iT_V + j(T_L + T_K) + (i-j)T_N)}{2} + \overline{W_{FR}}, j = 0,1,2,...,i-1 \quad (9)$$

Where $\frac{T_{SF} - (iT_V + j(T_L + T_K) + (i-j)T_N)}{2}$ is the average waiting time in the current super frame, T_{SF} is the average length of the super frame, and $\overline{W_{FR}}$ is the average waiting time in the next super frame and it is given by:

$$\overline{W_{FR,k}} = iT_V + k(T_L + T_K) + (i-1-k)T_N \quad (10)$$

Where k is the number of devices that have data packets to send among the $i-1$ devices that are polled before the i^{th} device in the next super frame. K is a random variable and it follows the binomial distribution as follows:

$$f(K) = \binom{i-1}{k} \rho^k (1-\rho)^{(i-1-k)}, k = 0,1,2,...,i-1 \quad (11)$$

Thus, $\overline{W_{FR}}$ is given by:

$$\overline{W_{FR}} = iT_V + (i-1)(\rho(T_L + T_K) + (1-\rho)T_N) \quad (12)$$

Substituting $\overline{W_{FR}}$ by its value in equation (9), thus $\overline{W_{i,j,EQ,C2}}$ is given by:

$$\overline{W_{i,j,EQ,C2}} = \frac{T_{SF} - (iT_V + j(T_L + T_K) + (i-j)T_N)}{2} + iT_V + (i-1)(\rho(T_L + T_K) + (1-\rho)T_N) \quad (13)$$

$P[C2]$ can be obtained as follows:

$$P[C2] = 1 - P[C1] = 1 - \frac{iT_V + j(T_L + T_K) + (i-1-j)T_N}{T_{SF}} \quad (14)$$

Substituting $\overline{W_{i,j,EQ,C1}}$, $\overline{W_{i,j,EQ,C2}}$, $P[C1]$ and $P[C2]$ by their values in equation (6). Thus, $\overline{W_{i,j,EQ}}$ can be obtained using the following equation:

$$\begin{aligned}\overline{W_{i,j,EQ}} = & \frac{T_{SF}}{2} + \frac{(iT_V + j(T_L + T_K) + (i-1-j)T_N)^2}{T_{SF}} \\ & - (iT_V + j(T_L + T_K) + (i-1-j)T_N) \\ & + (iT_V + (i-1)(\rho(T_L + T_K) + (1-\rho)T_N)) \\ & \times \frac{(T_{SF} - (iT - V + j(T_L + T_K) + (i-1-j)T_N))}{T_{SF}}\end{aligned} \quad (15)$$

Substituting $\overline{W_{i,j,EQ}}$ by its value in equation (4), thus $\overline{T_{i,j,EQ}}$ is given by:

$$\begin{aligned}\overline{T_{i,j,EQ}} = & \frac{T_{SF}}{2} + \frac{(iT_V + j(T_L + T_K) + (i-1-j)T_N)^2}{T_{SF}} \\ & - (iT_V + j(T_L + T_K) + (i-1-j)T_N) \\ & + (iT_V + (i-1)(\rho(T_L + T_K) + (1-\rho)T_N)) \\ & \times \frac{(T_{SF} - (iT - V + j(T_L + T_K) + (i-1-j)T_N))}{T_{SF}} \\ & + T_L\end{aligned} \quad (16)$$

Where j is random variable and has a binomial distribution as given in equation (11). Thus, $\overline{T_{i,EQ}}$ is given by:

$$\begin{aligned}\overline{T_{i,EQ}} &= \sum_{j=0}^{i-1} ((\overline{T_{i,j,EQ}}) \binom{i-1}{j} \rho^j (1-\rho)^{(i-1-j)}) \\ &= \frac{T_{SF}}{2} + \frac{\rho(T_L + T_K - T_N)^2 (i-1)(1-\rho)}{T_{SF}} + T_L\end{aligned} \quad (17)$$

To calculate $\overline{T_{i,NEQ}}$, it is assumed that there are N_Q packets wait in the device buffer. Thus, $\overline{T_{i,NEQ}}$ can be obtained by:

$$\overline{T_{i,NEQ}} = \overline{W_{i,NEQ}} + T_L \quad (18)$$

Where $\overline{W_{i,NEQ}}$ is the expected packet waiting time at the i^{th} device when the device buffer is not empty and can be obtained as follows:

$$\overline{W_{i,j,NEQ}} = P[C1]\overline{W_{i,j,NEQ,C1}} + P[C2]\overline{W_{i,j,NEQ,C2}} \quad (19)$$

Where $P[C1]$ and $\overline{W_{i,j,NEQ,C1}}$ are the probability and the waiting time, respectively for case1 and P[C2] and $\overline{W_{i,j,NEQ,C2}}$ are the probability and the waiting time, respectively for case2. Case1: the target packet arrives to the i^{th} device buffer, that contains N_Q packets, before receiving its polling order. Case2: the target packet arrives to the i^{th} device buffer after the device received its polling order.

Considering that each device transmits one packet at most every super frame. If the packet arrives to the i^{th}

device buffer, that contains N_Q packets, before receiving its polling order, that packet waits until one of N_Q packets gets served during the current super frame and the remaining $N_Q - 1$ packets are served in the next consecutives $N_Q - 1$ polling along N_{Q-1} super frames. Then, $\overline{W_{i,j,NEQ,C1}}$ can be given by:

$$\overline{W_{i,j,NEQ,C1}} = \frac{T_{SF} - (iT_V + (j+1)(T_L + T_K) + (i-1-j)T_N)}{2} + (\overline{N_Q} - 1)T_{SF} + (iT_V + (i-1)(\rho(T_L + T_K) + (1-\rho)T_N)) \quad (20)$$

If the packet arrives to the i^{th} device buffer after the device received its polling order, the packet waits until the current super frame ends and N_Q packets are served in the next consecutives N_Q polling along N_Q super frames. Then, $\overline{W_{i,j,NEQ,C2}}$ is given by:

$$\overline{W_{i,j,NEQ,C2}} = \frac{T_{SF} - (iT_V + (j+1)(T_L + T_K) + (i-1-j)T_N)}{2} + \overline{N_Q}T_{SF} + (iT_V + (i-1)(\rho(T_L + T_K) + (1-\rho)T_N)) \quad (21)$$

$P[C1]$ can be obtained by:

$$P[C1] = \frac{iTV + (j+1)(T_L + T_K) + (i-1-j)T_N}{T_{SF}} \quad (22)$$

and $P[C2]$ can be obtained by:

$$P[C1] = 1 - P[C1] = 1 - \frac{iTV + (j+1)(T_L + T_K) + (i-1-j)T_N}{T_{SF}} \quad (23)$$

Substituting $\overline{W_{i,j,NEQ,C1}}$, $\overline{W_{i,j,NEQ,C2}}$, $P[C1]$ and $P[C2]$ by their values in equation (19), $\overline{W_{i,j,NEQ}}$ can be obtained from the following equation:

$$\overline{W_{i,j,NEQ}} = \frac{T_{SF}}{2} - (iT_V + (j+1)(T_L + T_K) + (i-j)T_N) + \overline{N_Q}T_{SF} + (iT_V + (i-1)(\rho(T_L + T_K) + (1-\rho)T_N)) \quad (24)$$

Substituting $\overline{W_{i,j,NEQ}}$ by its value in equation (18), thus $\overline{T_{i,j,NEQ}}$ is given by:

$$\overline{T_{i,j,NEQ}} = \frac{T_{SF}}{2} - (iT_V + (j+1)(T_L + T_K) + (i-j)T_N) + \overline{N_Q}T_{SF} + (iT_V + (i-1)(\rho(T_L + T_K) + (1-\rho)T_N)) + T_L \quad (25)$$

Where j is random variable and has a binomial distribution as given in equation (11). Thus, $\overline{T_{i,NEQ}}$ is given by:

$$\overline{T_{i,NEQ}} = \sum_{j=0}^{i-1} \left((\overline{T_{i,j,NEQ}}) \binom{i-1}{j} \rho^j (1-\rho)^{(i-1-j)} \right) \quad (26)$$

Substituting $\overline{T_{i,EQ}}$, $\overline{T_{i,NEQ}}$, $P[EQ]$ and $P[NEQ]$ by their values from equations (17), (26), (3), and (2) in equation (1), thus $\overline{T_i}$ is given by:

$$\overline{T_i} = \frac{T_{SF}}{2} + \rho\overline{N_Q}T_{SF} - \rho T_K + \left(\frac{\rho(T_L + T_K - T_N)^2 (i-1)(1-\rho)}{T_{SF}} + T_L \right)(1-\rho) \quad (27)$$

$\overline{N_Q}$ can be calculated using the equation:

$$\overline{N_Q} = \sum_{i=0}^{\infty} \frac{iP[N = i, NEQ]}{P[NEQ]} = \sum_{i=0}^{\infty} \frac{iP[N = i]}{\rho} = \frac{\overline{N}}{\rho} \quad (28)$$

Where $P[N = i, NEQ]$ is the probability of the existence of i packets in the non-empty buffer and $\overline{N}$ is the average number of packets that arrive during $\overline{T_i}$ and is obtained by Littles law as follows:

$$\overline{N} = \lambda \overline{T_i} \quad (29)$$

Thus, $\overline{N_Q}$ is represented by:

$$\overline{N_Q} = \frac{\lambda \overline{T_i}}{\rho} \quad (30)$$

Substituting $\overline{N_Q}$ by its value in equation (27), therefore $\overline{T_i}$ can be obtained by:

$$\overline{T_i} = \frac{1}{1 - \lambda T_{SF}} \left(\frac{T_S F}{2} - \rho T_K + \left(\frac{\rho(T_L + T_K - T_N)^2 (i-1)(1-\rho)}{T_{SF}} + T_L \right)(1-\rho) \right) \quad (31)$$

T_{SF} can be given by:

$$T_{SF} = \overline{T_{CP}} + \overline{T_{CFP}} \quad (32)$$

Where $\overline{T_{CP}}$ and $\overline{T_{CFP}}$ are the average time length of CP and CFP, respectively.

$$\overline{T_{CFP}} = \frac{\overline{CFP}}{R} \quad (33)$$

Where $\overline{CFP}$ is the average length of CFP in bytes and R is the channel byte rate.

$$CFP = \sum_{i=1}^{N_D} (L_i + L_K) + (N - N_D) L_N + L_C + L_{Polls} \quad (34)$$

Where N is the total number of stations, N_D is the number of devices that have data frames to send in a single CFP, L_i is the length of the data frame from the device, i, in bytes, L_K , L_N , and L_C are the lengths of acknowledgment frame, nothing to send frame, CFEND frame, and device address, respectively.

In DLHPL, each device appends only the next device address instead of appending the full list in RSPL. Then

$$L_{Polls} = NL_A$$

Where L_A is the device address length in bytes.

CFP 's PGF can be given by:

$$CFP(z) = E\left(z^{\sum_{i=1}^{N_D} L_i - N_D(L_N - L_K)}\right) \times z^{(NL_N + L_C + NL_A)} \quad (35)$$

$\overline{CFP}$ can be obtained using the following equation:

$$\overline{CFP} = N\left(P(\frac{1}{\alpha} + L_K) + (1-P)L_N\right) + L_C + NL_A \quad (36)$$

Substituting $\overline{CFP}$ by its value in equation (33), $\overline{T_{CFP}}$ can be given by:

$$\overline{T_{CFP}} = \frac{N\left(P(\frac{1}{\alpha} + L_K) + (1-P)L_N\right) + L_C + NL_A}{R} \quad (37)$$

Substituting $\overline{T_{CFP}}$ by its value from equation (37) in equation (32), DLHPL super frame length, T_{SF} , can be given as follows:

$$T_{SF} = \overline{T_{CP}} - \frac{N\left(P(\frac{1}{\alpha} + L_K) + (1-P)L_N\right) + L_C + NL_A}{R} \quad (38)$$

Substituting T_{SF} by its value in equation (31), the expected packet delay in the i^{th} device for DLHPL, $\overline{T_i}$, can be given by:

$$\overline{T_i} = \frac{1}{1 - \lambda\left(\overline{T_{CP}} + \frac{N(P(\frac{1}{\alpha}+L_K)+(1-P)L_N)+L_C+NL_A}{R}\right)} \times \left[\frac{\left(\overline{T_{CP}} + \frac{N(P(\frac{1}{\alpha}+L_K)+(1-P)L_N)+L_C+NL_A}{R}\right)}{2} - \rho T_K + \left(\frac{\rho(T_L + T_K - T_N)^2(i-1)(1-\rho)}{\left(\overline{T_{CP}} + \frac{N(P(\frac{1}{\alpha}+L_K)+(1-P)L_N)+L_C+NL_A}{R}\right)} + T_L\right) \times (1-\rho)\right] \quad (39)$$

T_L can be given by $\frac{\frac{1}{\alpha}}{R}$, T_K can be given by $\frac{L_K}{R}$, and T_N can be given by $\frac{L_N}{R}$.

So

$$\overline{T_i} = \frac{1}{1 - \lambda\left(\frac{R\overline{T_{CP}}+N(P(\frac{1}{\alpha}+L_K)+(1-P)L_N)+L_C+NL_A}{R}\right)} \times \left[\left(\frac{R\overline{T_{CP}} + N(P(\frac{1}{\alpha}+L_K)+(1-P)L_N)+L_C+NL_A}{2R}\right) - \rho L_K + \left(\frac{\rho(\frac{1}{\alpha} + L_K - L_N)^2(i-1)(1-\rho)}{\left(\frac{R\overline{T_{CP}}+N(P(\frac{1}{\alpha}+L_K)+(1-P)L_N)+L_C+NL_A}{R}\right)} + \frac{1}{\alpha}\right) \times \frac{(1-\rho)}{R}\right] \quad (40)$$

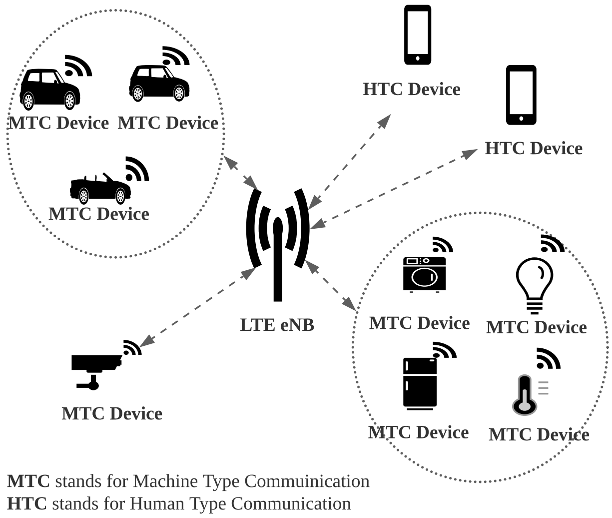

Fig. 1: MTC devices clustering.

Following the same manner, the expected packet delay in the i^{th} device for RSPL can be given as follows:

$$\overline{T_i} = \frac{1}{1 - \lambda\left(\frac{R\overline{T_{CP}}+N(P(\frac{1}{\alpha}+L_K)+(1-P)L_N)+L_C+(N(N+1)L_A/2)}{R}\right)} \times \left[\left(\frac{R\overline{T_{CP}} + N(P(\frac{1}{\alpha}+L_K)+(1-P)L_N)+L_C+(N(N+1)L_A/2)}{2R}\right) - \rho L_K + \left(\frac{\rho(\frac{1}{\alpha} + L_K - L_N)^2(i-1)(1-\rho)}{\left(\frac{R\overline{T_{CP}}+N(P(\frac{1}{\alpha}+L_K)+(1-P)L_N)+L_C+(N(N+1)L_A/2)}{R}\right)} + \frac{1}{\alpha}\right) \times \frac{(1-\rho)}{R}\right] \quad (41)$$

4 The Proposed Access Technique

In the proposed access technique, the MTC UEs are clustered into groups as shown in fig. 1 based on the geographical location using the k-means clustering algorithm [35]. A UE can access the LTE eNB individually without joining any group if it can't find near neighbors or it finds the near group size is large. The internal group communication, sharing the WLAN medium, and sharing eNB resources are controlled and managed by DLHPL MAC protocol. A UE, that joins a group, can transmit data locally using WLAN resources and at the same time globally outside the WLAN using LTE network resources via the eNB.

To transmit data frames locally, each UE transmits the data frame in its polling order. To transmit data frames outside the WLAN, the UE has two options: 1) using the uplink resources that were requested previously from eNB by the other group members and shared inside its group, 2) requesting a new uplink resource from the eNB if there are no shared resources or the time to get its polling order to use the shared resources are elapsed. If there are available shared uplink resources, the UE waits for its order to transmit the data using these shared resources. Otherwise, it performs RACH access and requests group uplink resources from the eNB. To ask for group resources that are shared inside WLAN from eNB, group scheduling is proposed. The group's scheduling looks like the semi-persistent scheduling [36, 37] with some modifications. In the group scheduling, the eNB assigns a Group Cell Radio Network Temporary Identifier (G-RNTI) to identify that the resources are used by a group and not for individual use. All UEs that use the same shared resources should use the same G-RNTI to address their data frames. After using the group resources by the requesting devices, these resources are shared between the WLAN group and are used to transmit outside the group without requesting resources from eNB. The resources are shared by broadcasting a resources' share frame. The UE broadcasts the frame in its polling order inside the WLAN group which is managed by DLHPL MAC protocol. If the next UE in the polling order has a data frame to send, it uses the shared resources. Otherwise, it immediately broadcasts a new resources' share frame. eNB releases the allocated resources when the consecutive idle slots reach the maximum number of idle slots. More details and the operation steps of the proposed work are presented in section 4.2.

4.1 Dynamic Separation of Preambles Set and Resources

Preamble set separation (PSS) scheme [16] was proposed as a solution to eliminate the effect of the massive access on LTE RACH. PSS scheme proposes constant preambles sets or RACH slots for HTC and MTC devices. The UE selects the preamble id or the RACH slot from the set reserved for its group. This fixed allocation scheme performs with HTC devices better than the performance with MTC devices when the number of access attempts of MTC devices is higher than the number of attempts of HTC devices accordingly, the resources of MTC devices are decreased dramatically.

In this paper, a Dynamic Preambles Set and PUSCH Resources Set Separation (DPSRSS) scheme is presented to solve this problem. Unlike the PSS scheme that divides only the preambles set, the proposed DPSRSS scheme divides the resources for RACH message#3, the uplink resources of PUSCH, as well as dividing the preambles set. The preambles set, RACH message#3 resources, and the PUSCH resources are divided dynamically and adaptively into two groups: HTC and MTC groups. The number of the allocated preambles set and PUSCH resources for every group change dynamically based on its access load history. The group with a higher load is allocated a larger number of preambles' set and PUSCH resources than the other groups that have a lower load.

In the proposed scheme, each group has an average access load ratio, which is calculated as the group access loads relative to all groups' access loads. The eNB updates the average access ratio using the exponential moving average for each group every UP (update period in milliseconds). Then the preambles set and the PUSCH resources are re-divided based on the updated groups' average access ratios and the eNB broadcasts the new preambles set distribution.

The operations of the proposed scheme are divided into two phases: (1) the access monitoring phase, and (2) the updating phase. The access monitoring phase oversees keeping track of each group's access, and the updating phase is responsible for updating the allocated preamble sets and PUSCH resources.

The steps of the proposed DPSRSS scheme are summarized as follows:

The initial step: each group has an access ratio with initial values, and the preambles sets and the PUSCH resources are distributed based on these initial values.

Access monitoring: when a device sends an access preamble, the eNB detects the device group and increases the group access counter by one.

Updating: After the triggering of the update period timer, the eNB calculates the new ratios of the groups based on the groups access counters in the interval that starts from the last update time to the current update phase time. The eNB uses the following equation to update the ratio of the i^{th} group in the j^{th} update phase.

$$A\_Ratio_{i,j} = (1-\alpha) \times A\_Ratio_{i,j-1} + \alpha \times \left(\frac{c_{i,j}}{(c_{1,j} + c_{2,j} + \ldots + c_{K,j})} \right), i = 1,2,\ldots,K \quad (42)$$

Where K is the number of groups, $A\_Ratio_{i,j}$ is the access ratio of group i in the update phase j, and $c_{i,j}$ is the access counter for group i in the update phase j.

After updating the access ratios, the allocated preambles set and the PUSCH resources are redistributed to be adaptive with the new groups' access ratios. Each group is allocated some preambles and some PUSCH resources equal to the multiplication of its ratio by the total available preambles number and total available PUSCH resources number, respectively.

4.2 The Proposed Access Technique in Action

The flow chart that is shown in fig. 2 illustrates the events of the proposed technique from the UE's side. The events of the proposed technique from the eNB side are illustrated in fig. 3.

The following steps summarize and present the full operations of the proposed work.

The steps of the proposed work from the EU's side are:

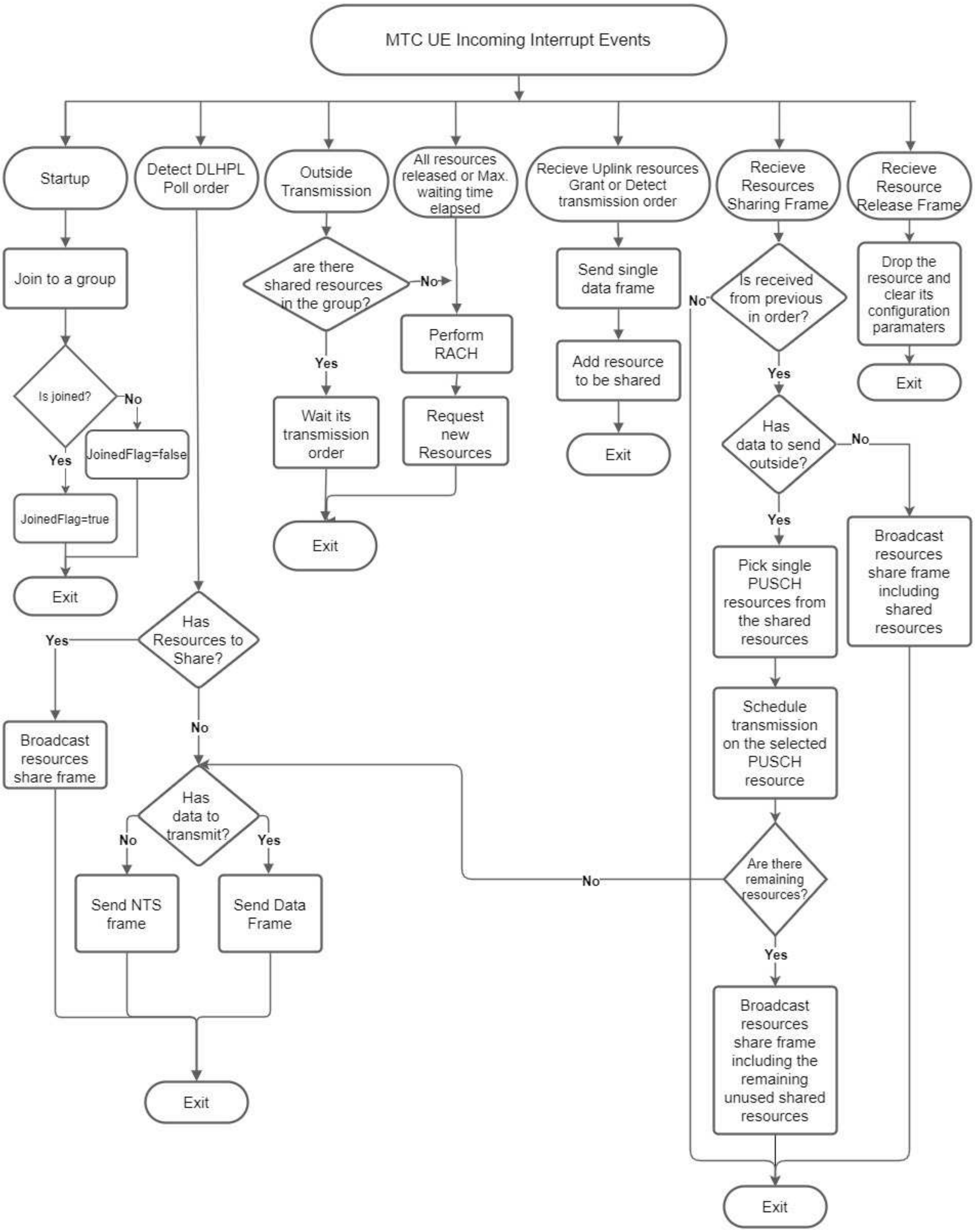

Fig. 2: The events of the proposed technique from the UE's side.

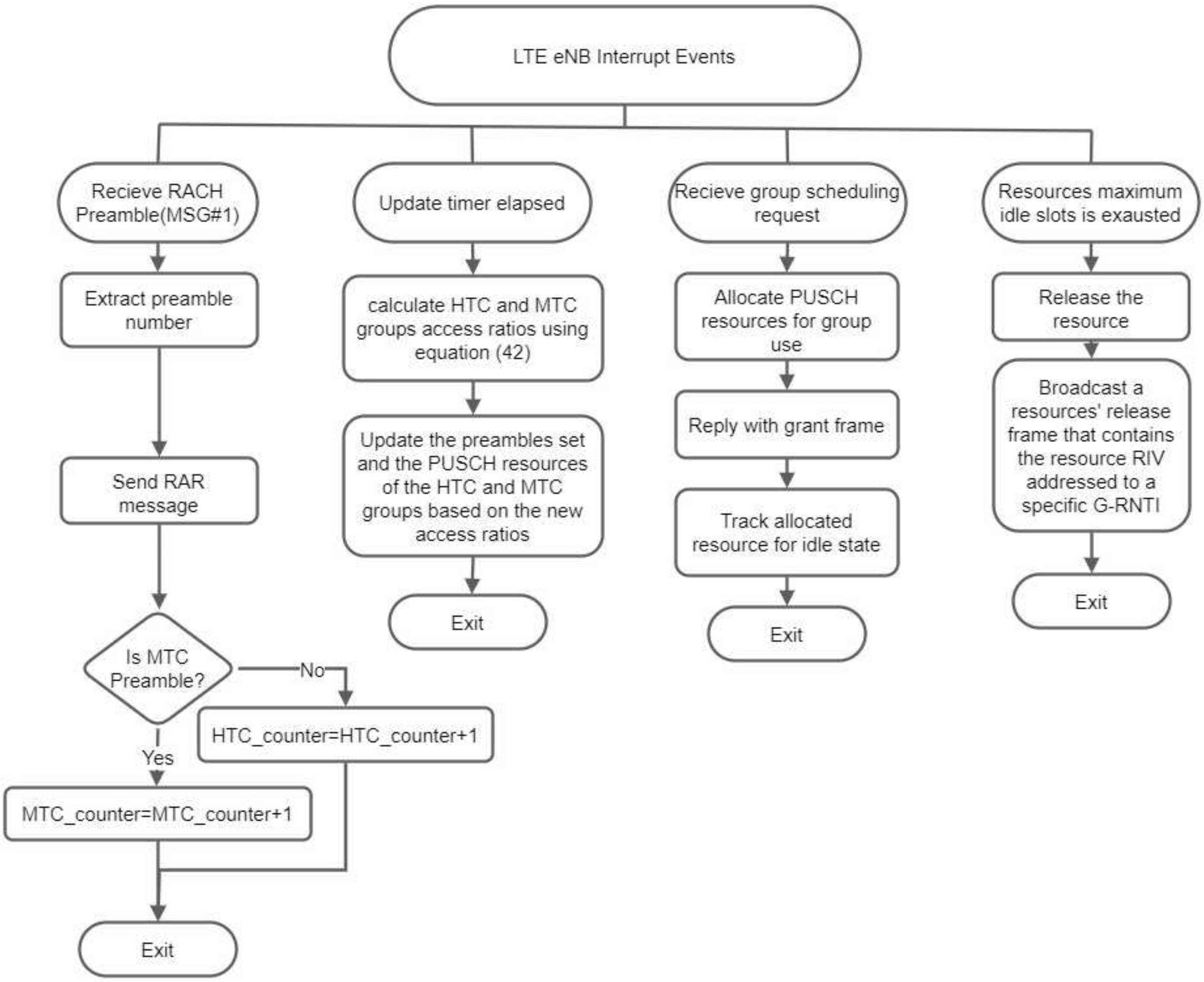

Fig. 3: The events of the proposed technique from the eNB side.

1. *Group joining:* The UE tries to find a near group and joins it. The joining operation is done using the DLHPL joining steps that were illustrated in section 2. If it could not join a group, it works as an individual and directly communicates with the eNB to request resources using the RACH procedure.
2. *Local data transmission:* If the UE joined a group and wants to send data locally inside the group, it waits for its order for the transmission based on the DLHPL polling list. Then it uses the local resources to transmit its data in its polling order.
3. *Global data transmission:* If the UE joined a group and wants to send data outside the group.
   (a) If there are shared PUSCH resources in its group WLAN,
      i. it waits for its order based on DLHPL polling list in any one of the shared resources.
      ii. it uses the resources to send its data outside the group in its polling order.
      iii. after finishing the transmission, it waits for its transmission order in its WLAN group polling list, and it sends a resource share frame for the resource that it finished its use.
   (b) Else if there are no shared resources or the waiting time for using the shared resources is higher than a threshold value, or all the shared resources inside its group are released,
      i. It accesses the eNB by performing the RACH procedure.
      ii. It requests new PUSCH resources for group use through sending group scheduling request to the eNB.
4. *Uplink resource granting:* If the UE succeeds to get PUSCH resource from the eNB,
   (a) it transmits a single data packet.

(b)it waits for its transmission order in its WLAN group polling list and transmits a resources' share frame including all available resources.

5.*Resource sharing frame receiving:* If the UE joined a group and it receives a resource share frame from its previous device.
   (a)If the UE data buffer is not empty,
      i.it reserves a single PUSCH resource from the shared resources and broadcasts a new resource share frame that includes all the shared resources except the first one that is reserved.
      ii.it schedules its transmission using the reserved resource to send a single data packet.
   (b)Otherwise, it broadcasts a new resource share frame that includes all the shared resources that the device received from its previous device.

6.*Release frame receiving:* if the UE receives a resources' release frame from eNB, it clears the resource configuration parameters.

The steps of the proposed work from the eNB side are:

1.*Access monitoring:* If the eNB receives a RACH preamble,
   (a)it responds to the preamble with the RAR message as mentioned in the standard RACH.
   (b)it Increases the access counters of the group that the preamble belongs to.

2.*Preamble set and resources updating:* If the Update period timer is elapsed,
   (a)the eNB updates the average access ratios of the HTC and MTC groups.
   (b)the eNB updates the preambles set and the PUSCH resources of the HTC and MTC groups based on the new access ratios.
   (c)the eNB broadcasts the new preambles set with the Master information.

3.*Group scheduling request receiving:* After receiving group scheduling request,
   (a)eNB allocates PUSCH resources for group use.
   (b)eNB sends resources grant frame.
   (c)eNB starts tracking the idle state of the allocated PUSCH resources.

4.*Resource releasing:* for each resource that reaches the maximum idle slots,
   (a)eNB releases the resource.
   (b)eNB broadcasts a resources' release frame that contains the resource RIV addressed to a specific G-RNTI.

It can be shown from the previous discussion as well as from the experimental results that will be presented in the next section that the proposed method has the following advantages compared with the other recently proposed techniques: (1) It offloads the massive access of MTC on eNB, (2) it avoids the single point of failure and relaying overhead through sharing the PUSCH resources, and (3) it provides lower preambles collisions, lower preambles retransmissions, lower RACH procedure delay, lower transfer delay, higher PUSH resources utilization, and lower power consumption.

5 Simulation Results

In this section, a comparison is held between the performance of the standard RACH scheme [12], the PSS scheme [16], and the proposed technique utilized with the standard RACH scheme and with the DPSRSS scheme. The results are obtained by a developed simulator using the LTE parameters that are listed in Table 1 and WLAN parameters that are listed in Table 2. The simulations are carried out under the following considerations: (1) there is no hidden terminal. (2) MTC packet size is small to be sent through only 1 slot. (3) The channel is reliable with no loss or interference. (4) The propagation delay is neglected.

All schemes are tested for 1000, 10000, 20000, and 30000 MTC devices. The arrivals of MTC devices follow beta distribution with values 3 and 4 for α and β respectively as recommended in 3gpp documentation [17, 38]. In addition, HTC devices are involved in the simulation with an arrival process of the arrival rate of λ device per second that follows poison distribution.

In the PSS scheme, two different preambles sets, (53/1) and (46/8), are used for MTC/HTC respectively. In the proposed access technique, the proposed DPSRSS scheme starts with (50/4) as preambles sets for MTC/HTC, respectively. The eNB updates the preambles sets and the uplink resources every 100 ms. with an update ratio equals 0.125. The PUSH resources, that are allocated for group use, can be used only for 1ms every Group Scheduling Interval (GS_Interval). The values of 10 ms. and 40 ms. are used interchangeably as GS_Interval, and the values of 2 and 4 slots are used interchangeably as a maximum number of idle slots for PUSCH resources release. MTC devices are clustered into 600 clusters. The MTC device decides to access eNB directly when the packet queuing delay reaches 200 ms..

The performances of the access schemes are compared using the following performance metrics:

1.*Preambles Collision Rate (PCR):* it is the number of preambles collision occurrences divided by the total available preambles.

2.*Access Success Probability (ASP):* it is the number of successful RACH attempts divided by all RACH attempts.

3.*Average Transmission Opportunities (ATO):* it is the ratio of the total number of granted resources divided by the total number of arrivals per device.

4.*PUSCH Resources Utilization (PRU):* It is the total bytes, from HTC and MTC devices, sent successfully toward the eNB on PUSCH divided by the PUSCH capacity.

Table 1: LTE network simulation parameters

Parameter	Value
MTC devices	1000, 10000, 20000, and 30000 devices
MTC devices' arrival distribution function	Beta distribution
HTC arrivals	7 call/seconds
Channel bandwidth	5 MHZ (25 RB)
Cell radius	1 Km
Preambles	54
PRACH configuration index	6
PUSCH periodicity	5 subframes
Maximum number of preamble transmission	10
Number of UL grants per RAR	3
ra-ResponseWindowSize	5 subframes
mac-ContentionResolutionTimer	48 subframes
Backoff Indicator	20 ms

Table 2: WLAN network parameters

Parameter	Value
Contention Period Time	3000 Microseconds
Max Back off	500 Microseconds
Data Rate	12 Mbps
DIFTime	50 Microseconds
SIFTime	50 Microseconds
Control Frame Length	20 Bytes
ACK Frame Length	20 Bytes
CFEnd Frame Length	20 Bytes

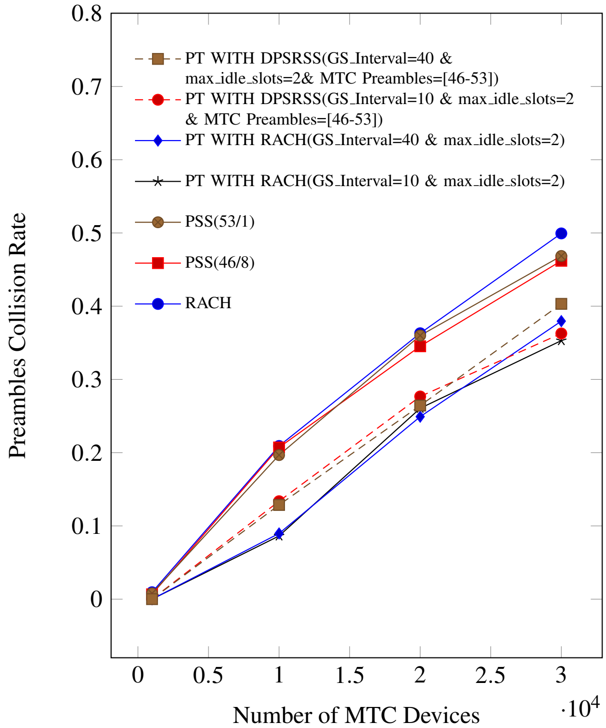

Fig. 4: Preamble collision rate for RACH, PSS, and the proposed technique (PT) utilized with the standard RACH and with the proposed DPSRSS scheme.

5.*Average Access Delay (AAD):* it is the average delay elapsed for the successful RACH attempts and it equals the RACH procedure delay.

6.*Average Transfer Delay (ATD):* it is the average delay elapsed from the packet arrival at the device buffer until it leaves the device buffer and is sent successfully toward eNB.

Figs. 4 to 10 show PCR, ASP, ATO, PRU, AAD, and ATD, respectively, for the standard RACH, PSS, and the proposed technique (PT) utilized with the standard RACH and DPSRSS schemes. From the figures, it can be shown that the proposed technique utilized with the standard RACH and DPSRSS schemes provides a lower PCR, higher ASP, higher ATO, higher PRU, lower AAD, and lower ATD than both RACH and PSS. The high performance of the proposed method is a result of dividing MTC devices into groups and enabling the resources sharing inside the group WLAN. Resource sharing inside the group without accessing the eNB reduces the number of devices that are trying to access the eNB, consequently reduces the preambles collisions, reduces the preambles' retransmission, reduces the access delay, increases the opportunity to get uplink resources, and reduces the transfer delay.

It can be shown from figs. 4, 6 and 7 that the proposed technique utilized with the RACH scheme provides a lower PCR, higher ASP for MTC, higher ATO for MTC than the proposed technique utilized with the proposed DPSRSS scheme. This is because DPSRSS divides the preambles set, RACH resources, PUSH resources between MTC devices and HTC devices dynamically based on the load and sets lower limits of the allocated preambles set, RACH resources, and PUSH resources for HTC devices to avoid the bad effects of MTCs massive access on HTC performance. Therefore, MTC devices, in DPSRSS, content on a smaller set of preambles, RACH resource, and PUSH resource than RACH. However, utilizing DPSRSS successes in avoiding the bad effect of the massive MTC access on HTC where it provides ASP with value 1 for HTC devices in all simulations performed that involved number of MTC devices ranges from 1000 to 30000 MTC devices as shown from fig. 5. Moreover, it provides higher PRU and lower ATD than utilizing RACH as shown in figs. 8 and 10.

It can be shown from figs. 7 and 8 that the proposed technique utilized with the RACH scheme and the proposed DPSRSS provides a lower ATO and PRU than the standard RACH and PSS schemes only for the small number of MTC devices. This is because in the case of low traffic in the proposed technique, most of the

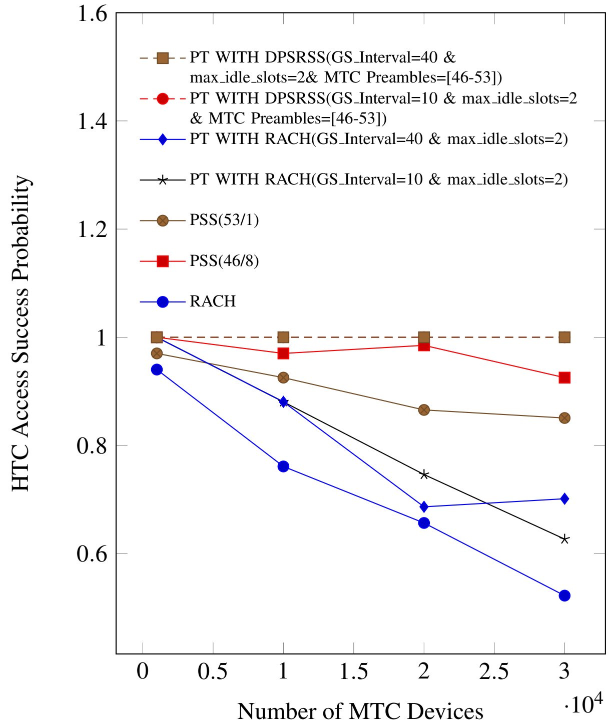

Fig. 5: HTC access success probability for RACH, PSS, and the proposed technique (PT) utilized with the standard RACH and with the proposed DPSRSS scheme.

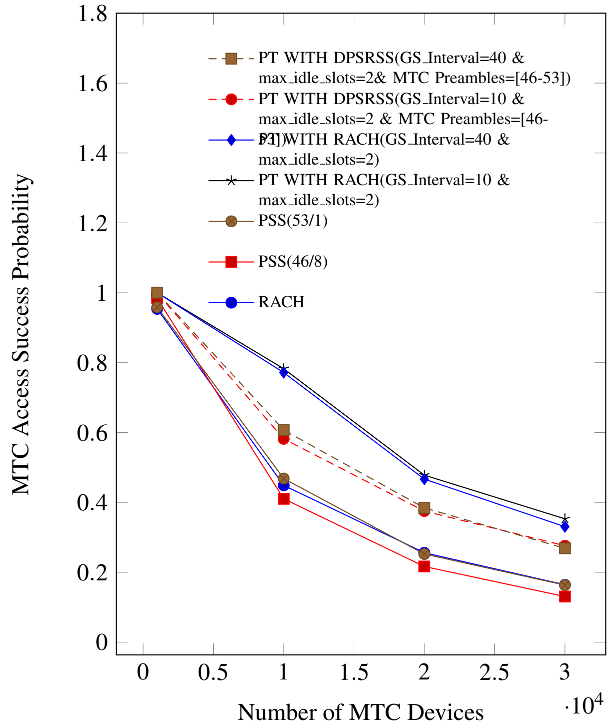

Fig. 6: MTC access success probability for RACH, PSS, and the proposed technique (PT) utilized with the standard RACH and the proposed DPSRSS scheme.

allocated resources are used very few times and are released after the idle period. Consequently, there are many wasted idle slots which cannot be used by other groups which decreases the opportunity of other groups to get resources and decreases the resources' utilization. But with the increase of the number of MTC devices in the proposed technique, the MTC traffic increases, and the probability of PUSH resources releasing decreases. Consequently, many packets can be sent using the same shared PUSH resources within a small delay without the need to request new resources directly from the eNB. This is shown also in fig. 10 in which the ATD of the proposed technique utilized with the RACH scheme and the proposed DPSRSS decreases with the increase of the number of MTC devices.

Recalling that the PUSH resources that are allocated for group use can be used only for 1ms every GS_Interval. So, the increase of GS_Interval results in: (1) allocating the PUSH resource for many slots within the GS_Interval as well as increasing the MTC devices opportunity to get PUSH resources and decreasing the probability of releasing PUSH resources because of the larger idle interval. Thus, it can be shown, from fig. 7, that using the GS_Interval value of 40ms in the proposed technique provides ATO higher than the proposed technique using the GS_Interval value of 10ms. (2) The packet queuing delay value increases to reach the maximum packet queuing delay (200ms) faster which results in increasing the number of devices that access the eNB directly. Thus, it can be shown, from fig. 4, that using the GS_Interval value of 40ms provides higher PCR than using the GS_Interval value of 10ms in case of the high load in the proposed technique.

6 Conclusion

In this paper, a new access technique based on the clustering approach is proposed to deal effectively with the MTC characteristics and requirements over the LTE network. In the proposed technique, MTC devices are divided into clusters based on their graphical location. The MTC devices inside the same cluster share the uplink resources that are allocated from the LTE network. The proposed technique minimizes the massive access of MTC devices on the LTE network and avoids the single point of failure and relaying operations overhead using the clustering approach and through sharing the uplink resources instead of using a relay/helper node. The WLAN's devices that accomplish the RACH procedure and succeed in getting resources from the eNB share these resources with its group for a fixed interval. All the devices inside the WLAN can send their data frames

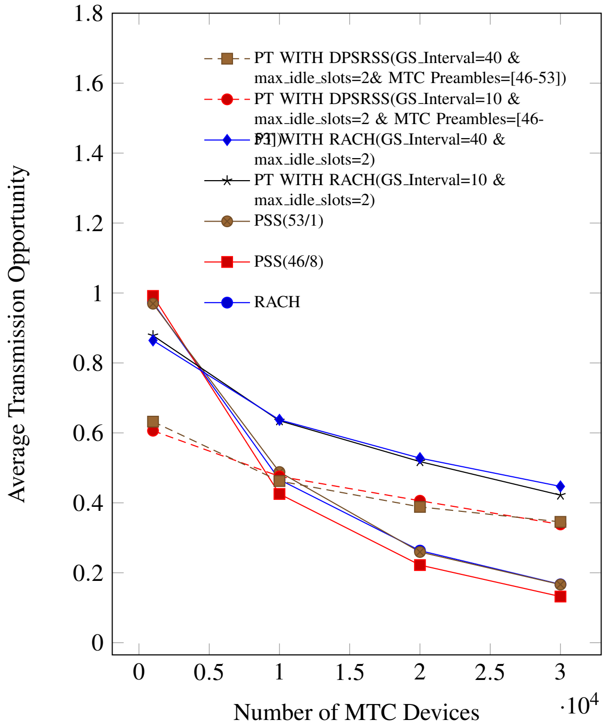

Fig. 7: Average transmission opportunity for RACH, PSS, and the proposed technique (PT) utilized with the standard RACH and the proposed DPSRSS scheme.

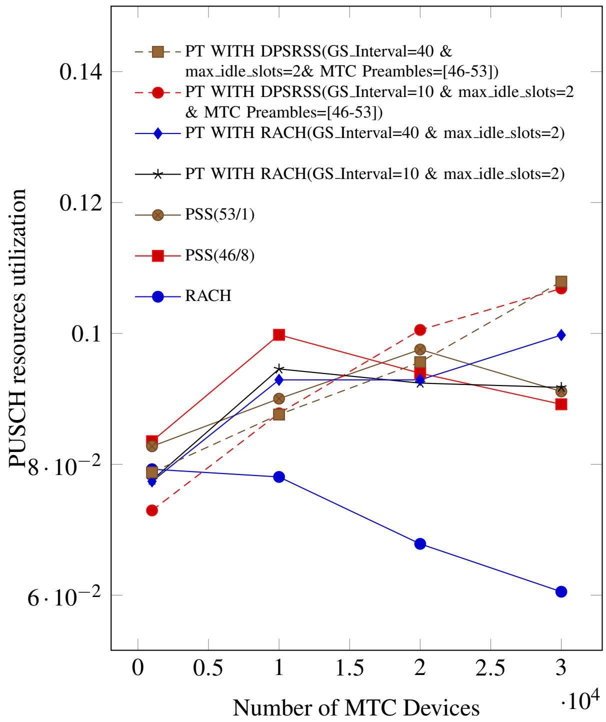

Fig. 8: PUSCH resources utilization for RACH, PSS, and the proposed technique (PT) utilized with the standard RACH and the proposed DPSRSS scheme.

directly using the shared resources without relaying them to a cluster head. DLHPL WLAN MAC protocol is used for internal group communication management.

The simulation results showed that the proposed technique provides, higher access probability, higher transmission opportunity, lower preambles collisions rate, lower preambles' retransmission rate, lower access delay, lower packet transfer delay, lower overhead, higher throughput, and higher uplink resources utilization than other works.

Also, a Dynamic Preambles Set and Resources Set Separation (DPSRSS) scheme is proposed, in this paper, to minimize the bad effect of the MTC massive access on HTC performance. DPSRSS divides the preambles set and the uplink resources between HTC and MTC groups dynamically based on the load of each HTC and MTC. Moreover, it sets lower limits of those preambles set and uplink resources reserved for HTC. From the simulation results, the proposed technique with the DPSRSS scheme provides a higher success rate for HTC than the proposed technique with the RACH scheme.

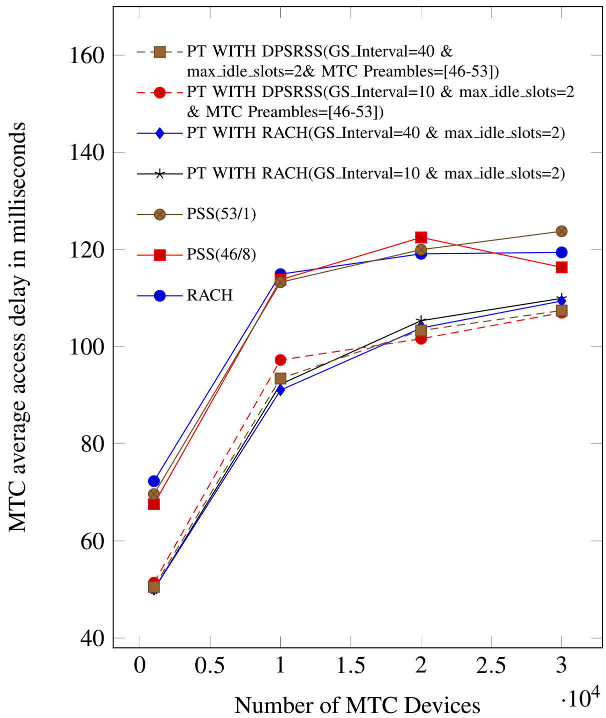

Fig. 9: MTC average access delay for RACH, PSS, and the proposed technique (PT) utilized with the standard RACH and the proposed DPSRSS scheme.

Conflict of interest

The authors declare that they have no conflict of interest.

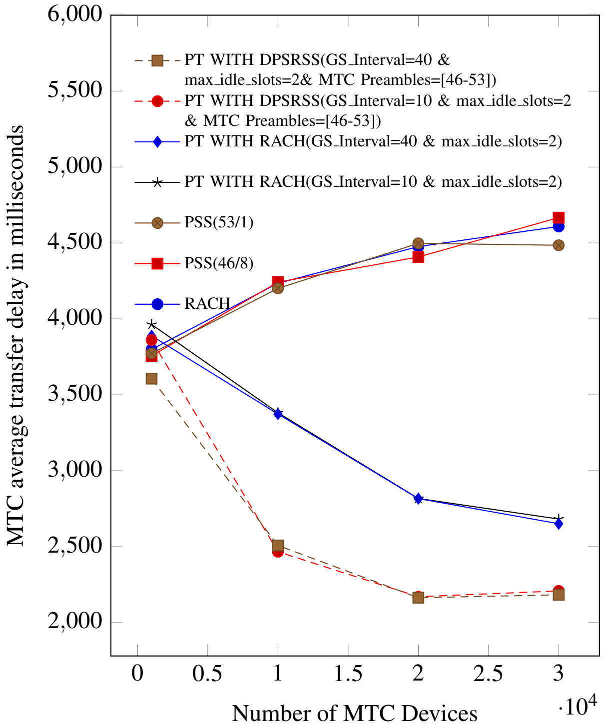

Fig. 10: MTC average transfer delay for RACH, PSS, and the proposed technique (PT) utilized with the standard RACH and the proposed DPSRSS scheme.

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